

# Kinematical correlations of dielectrons from semileptonic decays of heavy mesons and Drell-Yan processes at BNL RHIC

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## Abstract

We discuss kinematical correlations between charged leptons from semileptonic decays of open charm/bottom, leptons produced in the Drell-Yan mechanism as well as some other mechanisms not included so far in the literature in proton-proton scattering at BNL RHIC. The distributions of charm and bottom quarks/antiquarks are calculated in the framework of the  $k_t$ -factorization approach. For this calculation we use different unintegrated parton distributions from the literature. The hadronization of heavy quarks is done with the help of well-known fragmentation functions. Uncertainties of our predictions related to heavy quark masses, factorization and renormalization scales as well as due to the choice of fragmentation model are also discussed. We use semileptonic decay functions found by fitting recent semileptonic data obtained by the CLEO and BABAR collaborations. The Drell-Yan processes were calculated including transverse momenta of quarks and antiquarks, using the Kwieciński parton distributions. We have also took into consideration reactions initiated by purely QED  $\gamma^*\gamma^*$ -fusion in elastic and inelastic pp collisions as well as recently proposed diffractive mechanism of exclusive charm-anticharm production. The contribution of the later mechanism is rather small. We get good description of the dilepton invariant mass spectrum measured recently by the PHENIX collaboration and present predictions for the dilepton pair transverse momentum distribution as well as distribution in azimuthal angle between electron and positron.

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## I. INTRODUCTION

Recently the PHENIX collaboration has measured dilepton invariant mass spectrum from 0 to 8 GeV in proton-proton collisions at  $\sqrt{s} = 200$  GeV [1]. It is commonly believed that the main contribution to the dielectron continuum comes from so-called nonphotonic electrons which are produced mainly in semileptonic decays of charm and bottom mesons. Up to now, production of open charm and bottom was studied only in inclusive measurements of charmed mesons [2] and electrons [3] and only inclusive observables were calculated in pQCD approach [4, 5]. Such predictions give rather good description of the experimental data, however, the theoretical uncertainties are quite large which makes the situation somewhat clouded and prevents definite conclusions.

Some time ago we have studied kinematical correlations of  $c\bar{c}$  quarks [6], which is, however, difficult to study experimentally. High luminosity and in a consequence better statistics at present colliders gives a new possibility to study not only inclusive distributions but also correlations between outgoing particles (meson-meson, meson-electron or electron-electron). Kinematical correlations constitute an alternative method to pin down the cross section for charm and bottom production. It gives also a great possibility to separate charm and bottom contributions which has a crucial meaning for understanding the character of heavy quarks interactions with the matter created in high energy nuclear collisions [7].

## II. FORMALISM

The  $k_t$ -factorization method is very useful to study correlations between  $c\bar{c}$  [6] and  $e^+e^-$  from the Drell-Yan processes [8]. In our calculations we take under consideration not only leptons from open charm/bottom decays but also leptons produced in Drell-Yan process, as well as leptons coming from elastic and inelastic processes initiated by photon-photon fusion. In the case of elastic reaction we follow exact momentum space calculations with 4-body phase space (see e.g. [9]) and for inelastic scattering we have applied unique (collinear) photon distributions in the nucleon MRST2004 [10].

### A. Dileptons from semileptonic decays

The electrons from semileptonic decays are produced in a three-stage process. The whole procedure can be written in the following schematic way:

$$\frac{d\sigma^e}{dyd^2p} = \frac{d\sigma^Q}{dyd^2p} \otimes D_{Q \rightarrow h} \otimes f_{h \rightarrow e} , \quad (2.1)$$

where the symbol  $\otimes$  denotes a generic convolution. The first term is responsible for production of heavy quarks/antiquarks (see Fig.1). Next step is the process of formation of heavy mesons and the last ingredient is semileptonic decay of heavy mesons to electrons/positrons. The inclusive production of heavy quark/antiquark pairs can be calculated in the framework of the  $k_t$ -factorization [11]. In this approach transverse momenta of initial partons are included and emission of gluons is encoded in a so-called unintegrated gluon, in general parton, distributions. In the leading-order approximation within the  $k_t$ -factorization approach the

differential cross section for the  $Q\bar{Q}$  or Drell-Yan process can be written as:

$$\frac{d\sigma}{dy_1 dp_{1t} dy_2 dp_{2t} d\phi} = \sum_{i,j} \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2(x_1 x_2 s)^2} |\overline{\mathcal{M}}_{ij}|^2 \delta^2(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}) \mathcal{F}_i(x_1, \kappa_{1,t}^2) \mathcal{F}_j(x_2, \kappa_{2,t}^2), \quad (2.2)$$

where  $\mathcal{F}_i(x_1, \kappa_{1,t}^2)$  and  $\mathcal{F}_j(x_2, \kappa_{2,t}^2)$  are the unintegrated gluon (parton) distribution functions (UPDFs). The longitudinal momentum fractions can be calculated as

$$\begin{aligned} x_1 &= \frac{m_{1t}}{\sqrt{s}} \exp(y_1) + \frac{m_{2t}}{\sqrt{s}} \exp(y_2), \\ x_2 &= \frac{m_{1t}}{\sqrt{s}} \exp(-y_1) + \frac{m_{2t}}{\sqrt{s}} \exp(-y_2), \end{aligned} \quad (2.3)$$

where  $y_1$  and  $y_2$  are rapidities of heavy quark and heavy antiquark, and  $m_{1t}$  and  $m_{2t}$  are their transverse masses.

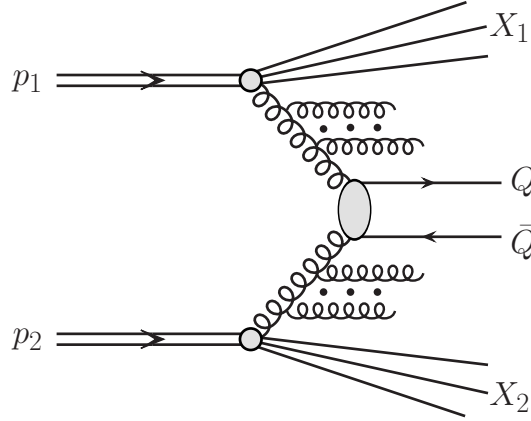


FIG. 1: The dominant mechanism of the  $c\bar{c}$  and  $b\bar{b}$  production at high energy. The emission of several extra gluons is included in the unintegrated gluon (parton) distributions used in the formalism.

There are two types of the LO  $2 \rightarrow 2$  subprocesses which contribute to heavy quarks production,  $gg \rightarrow Q\bar{Q}$  and  $q\bar{q} \rightarrow Q\bar{Q}$ . The first mechanism dominates at large energies and the second one near the threshold. Only  $gg \rightarrow Q\bar{Q}$  mechanism is included here. We use off-shell matrix elements corresponding to off-shell kinematics so hard amplitude depends on transverse momenta (virtualities of initial gluons) in the exact way. At relatively low RHIC energies rather intermediate  $x$ -values become relevant so the Kwiecinski UGDFs seem applicable in this case [12]. However, to show the uncertainty of our predictions resulting from different approaches in calculating unintegrated parton distributions we have also used Kimber-Martin-Ryskin (KMR) [13] and Kutak-Stasto models [14]. All of them have different theoretical background. It is therefore very interesting to compare such results with the PHENIX data and verify applicability of these UGDFs at RHIC. In the case of the Kwiecinski distributions we fix the renormalization and factorization scales to standard values  $\mu_R^2 = \mu_F^2 = 4m_Q^2$ . Using the KMR UGDF the mostly used set of these parameters in the context of inclusive heavy quark production is  $\mu_R^2 = 4m_Q^2$  and  $\mu_F^2 = M_{Q\bar{Q}}^2$ , where  $M_{Q\bar{Q}}$  is the invariant mass of the  $Q\bar{Q}$  pair.

The hadronization of heavy quarks is usually done with the help of fragmentation functions. The inclusive distributions of hadrons can be obtained through a convolution of inclusive distributions of heavy quarks/antiquarks and  $Q \rightarrow h$  fragmentation functions:

$$\frac{d\sigma(y_1, p_{1t}^H, y_2, p_{2t}^H, \phi)}{dy_1 dp_{1t}^H dy_2 dp_{2t}^H d\phi} \approx \int \frac{D_{Q \rightarrow H}(z_1)}{z_1} \cdot \frac{D_{\bar{Q} \rightarrow \bar{H}}(z_2)}{z_2} \cdot \frac{d\sigma(y_1, p_{1t}^Q, y_2, p_{2t}^Q, \phi)}{dy_1 dp_{1t}^Q dy_2 dp_{2t}^Q d\phi} dz_1 dz_2, \quad (2.4)$$

where:  $p_{1t}^Q = \frac{p_{1t}^H}{z_1}$ ,  $p_{2t}^Q = \frac{p_{2t}^H}{z_2}$ , where meson longitudinal fractions  $z_1, z_2 \in (0, 1)$ . We have made approximation assuming that  $y_1, y_2, \phi$  are unchanged in the fragmentation process.

There are several models of fragmentation functions in the literature. Here we mostly use the Peterson fragmentation function [15]. However, to check the sensitivity of our results to the choice of the fragmentation model, we have also applied fragmentation functions proposed by Kartvelishvili et al. [16] and Braaten et al. [17].

Recently the CLEO and BABAR collaborations have measured very precisely the spectrum of electrons/positrons coming from the weak decays of  $D$  and  $B$  mesons, respectively [18]. These functions can in principle be calculated. This introduces, however, some model uncertainties and requires inclusion of all final state channels explicitly. An alternative is to use proper experimental input which after renormalizing to experimental branching fractions can be used to generate electrons/positrons in a Monte Carlo approach. The electrons (positrons) are generated isotropically in the heavy meson rest frame. In the present paper we use parametrizations of the decay functions found in Ref.[5].

## B. Drell-Yan dileptons

The electron and positron produced in the Drell-Yan mechanism are naturally correlated. We have shown recently [8] how to use the transverse momentum dependent parton (quark, antiquark) distributions to obtain several differential distributions. A basic diagram of the mechanism is shown in Fig.2. In our calculations here we follow Ref.[8] and use the Kwiecinski parton distributions. Here the off-shellness of quark/antiquark is included in the kinematics and the matrix element taken here in the on-shell form expressed in terms of the subprocess invariants calculated with the off-shell condition. This is not fully consistent but avoids problems when on-shell momenta of quarks and on-shell matrix element are used [19, 20]. In any case the result of our approach is not very different than that for the collinear approach but includes kinematical effect of transverse momenta which is crucial to understand e.g. azimuthal correlations and distributions in transverse momentum of the dilepton pair, impossible to address in the collinear approach.

The differential cross section for the 0-th order contribution including quark/antiquark transverse momenta can be written as:

$$\begin{aligned} \frac{d\sigma}{dy_1 dy_2 d^2 p_{1t} d^2 p_{2t}} = \sum_f \int \frac{d^2 \kappa_{1t}}{\pi} \frac{d^2 \kappa_{2t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} \\ \delta^2(\vec{\kappa}_{1t} + \vec{\kappa}_{2t} - \vec{p}_{1t} - \vec{p}_{2t}) [\mathcal{F}_{q_f}(x_1, \kappa_{1t}^2, \mu_F^2) \mathcal{F}_{\bar{q}_f}(x_2, \kappa_{2t}^2, \mu_F^2) \overline{|M(q\bar{q} \rightarrow e^+ e^-)|^2} \\ + \mathcal{F}_{\bar{q}_f}(x_1, \kappa_{1t}^2, \mu_F^2) \mathcal{F}_{q_f}(x_2, \kappa_{2t}^2, \mu_F^2) \overline{|M(q\bar{q} \rightarrow e^+ e^-)|^2}] , \end{aligned} \quad (2.5)$$

where  $\mathcal{F}_i(x_1, \kappa_{1t}^2)$  and  $\mathcal{F}_i(x_2, \kappa_{2t}^2)$  are unintegrated quark/antiquark distributions in hadron  $h_1$  and  $h_2$ , respectively.

The longitudinal momentum fractions are evaluated in terms of final lepton rapidities and transverse momenta:

$$\begin{aligned} x_1 &= \frac{m_{1t}}{\sqrt{s}} \exp(y_1) + \frac{m_{2t}}{\sqrt{s}} \exp(y_2) , \\ x_2 &= \frac{m_{1t}}{\sqrt{s}} \exp(-y_1) + \frac{m_{2t}}{\sqrt{s}} \exp(-y_2), \end{aligned} \quad (2.6)$$

where  $m_t = \sqrt{p_t^2 + m^2}$  are transverse masses of electron and positron.

The delta function in Eq.(2.5) can be eliminated as e.g. in Refs.[6].

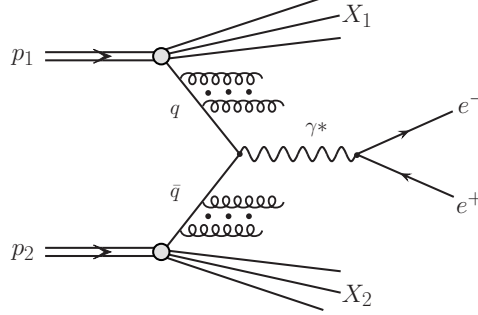


FIG. 2: The Drell-Yan mechanism of the dielectron pair production. The extra gluon emissions are included in the formalism of unintegrated parton distributions.

### C. QED $\gamma^*\gamma^*$ elastic and inelastic production of dileptons

The matrix element for the  $pp \rightarrow ppe^+e^-$  reaction via  $\gamma^*\gamma^*$ -fusion (see Fig.3) can be approximately written as

$$\mathcal{M}^{\gamma^*\gamma^*} \approx eF_1(t_1) \frac{(p_1 + p'_1)^\nu}{t_1} V_{\mu\nu}^{\gamma^*\gamma^*}(q_1, q_2) \frac{(p_2 + p'_2)^\mu}{t_2} eF_1(t_2), \quad (2.7)$$

where  $F_1(t_1)$  and  $F_1(t_2)$  are Dirac proton electromagnetic form factors, and the  $\gamma^*\gamma^* \rightarrow e^+e^-$  vertex has the form

$$V_{\lambda_q \lambda_{\bar{q}}, \mu\nu}^{\gamma^*\gamma^*} = e^2 \bar{u}_{\lambda_q}(k_1) \left( \gamma^\nu \frac{\hat{q}_1 - \hat{k}_1 - m}{(q_1 - k_1)^2 - m^2} \gamma^\mu - \gamma^\mu \frac{\hat{q}_1 - \hat{k}_2 + m}{(q_1 - k_2)^2 - m^2} \gamma^\nu \right) v_{\lambda_{\bar{q}}}(k_2). \quad (2.8)$$

The above formulae are used to calculate differential cross section via exact integration in the full 4-body phase-space. The details can be found e.g. in Ref. [9]. We shall call this contribution double elastic for brevity.

In addition, there are components when one of the protons, or even both (see Fig.3), do not survive the collision. Corresponding contributions will be called single and double inelastic processes respectively. The double inelastic contribution can be calculated as the gluon-gluon contribution in the parton model by replacing gluon distributions in the nucleon by corresponding photon distributions. Only one group discussed photon distributions in the nucleon [10]. The corresponding cross section can be calculated as

$$\frac{d\sigma}{dy_1 dy_2 d^2p_t} = \frac{1}{16\pi^2 \hat{s}^2} x_1 f_{\gamma/p}(x_1, \mu^2) x_2 f_{\gamma/p}(x_2, \mu^2) |\overline{\mathcal{M}_{\gamma\gamma \rightarrow e^+e^-}}|^2. \quad (2.9)$$

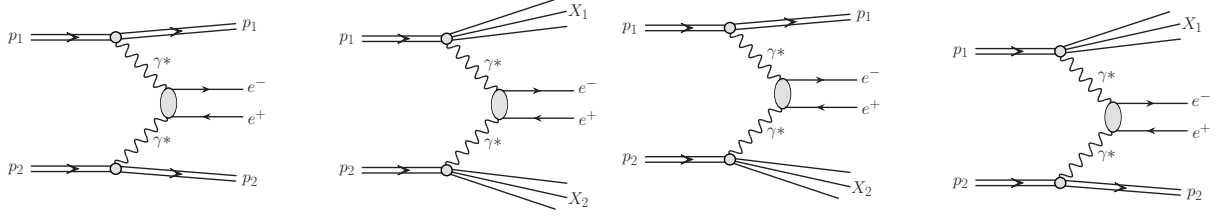


FIG. 3: Diagrammatic representation of processes initiate by photon-photon subprocesses: double-elastic, double-inelastic, inelastic-elastic and elastic-inelastic.

The matrix element can be found in several text books. The cross section for single inelastic process can be calculated by a replacement of one of  $f_{\gamma/p}(x, \mu^2)$  by  $f_{\gamma/p}^{el}(x)$  which is often called elastic photon flux factor. Relevant formulae can be found in [21].

#### D. Exclusive double-diffractive production of open charm

Recently, our group has calculated, for the first time in the literature, the exclusive double diffractive (EDD) production of open charm [22]. A sketch of this mechanism is shown in Fig. 4.

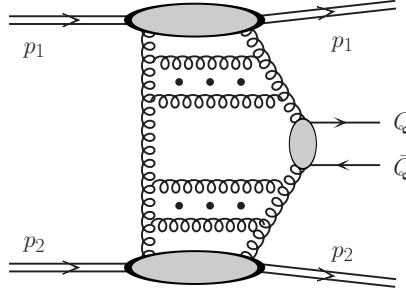


FIG. 4: The mechanism of exclusive double-diffractive production of open charm.

The  $pp \rightarrow p(c\bar{c})p$  reaction is treated as a genuine 4-body process with exact kinematics. This can be easily used to apply kinematical cuts required by experiments. According to the Kaidalov-Khoze-Martin-Ryskin (KKMR) approach used previously for the exclusive Higgs boson production [23], the amplitude of the exclusive diffractive  $q\bar{q}$  pair production  $pp \rightarrow p(q\bar{q})p$  can be written as [22]

$$\mathcal{M}_{\lambda_q \lambda_{\bar{q}}}^{pp \rightarrow ppq\bar{q}}(p'_1, p'_2, k_1, k_2) = s \cdot \pi^2 \frac{1}{2} \frac{\delta_{c_1 c_2}}{N_c^2 - 1} \Im \int d^2 q_{0,t} V_{\lambda_q \lambda_{\bar{q}}}^{c_1 c_2}(q_1, q_2, k_1, k_2) \frac{f_{g,1}^{\text{off}}(x_1, x'_1, q_{0,t}^2, q_{1,t}^2, t_1) f_{g,2}^{\text{off}}(x_2, x'_2, q_{0,t}^2, q_{2,t}^2, t_2)}{q_{0,t}^2 q_{1,t}^2 q_{2,t}^2}, \quad (2.10)$$

where  $\lambda_q, \lambda_{\bar{q}}$  are helicities of heavy  $q$  and  $\bar{q}$ , respectively. Above  $f_{g,1}^{\text{off}}$  and  $f_{g,2}^{\text{off}}$  are the off-diagonal unintegrated gluon distributions in nucleon 1 and 2, respectively.

The vertex factor  $V_{\lambda_q \lambda_{\bar{q}}}^{c_1 c_2} = V_{\lambda_q \lambda_{\bar{q}}}^{c_1 c_2}(q_1, q_2, k_1, k_2)$  in expression (2.10) is the production amplitude of a pair of massive quark  $q$  and antiquark  $\bar{q}$  with helicities  $\lambda_q, \lambda_{\bar{q}}$  and momenta

$k_1$ ,  $k_2$ , respectively. The bare amplitude above is subjected to absorption corrections which depend on collision energy and on the spin-parity of the produced central system.

In the KMR approach the off-diagonal parton distributions are calculated as

$$f_g^{\text{KMR}}(x, Q_t^2, \mu^2, t) = R_g \frac{d[xg(x, k_t^2)S_{1/2}(k_t^2, \mu^2)]}{d \log k_t^2} \Big|_{k_t^2=Q_t^2} F(t) , \quad (2.11)$$

where  $S_{1/2}(q_t^2, \mu^2)$  is a Sudakov-like form factor relevant for the case under consideration [24]. The factor  $R_g$  here is the skewedness parameter and at the RHIC energy the value  $R_g \sim 1.4$  seems to be relevant.

In the present calculation we use standard GRV95 collinear gluon distributions [25]. For this process we take the renormalization and factorization scales to be  $\mu_R^2 = \mu_F^2 = M_{c\bar{c}}^2/4$  as in Ref.[22]. Absorption effects are included approximately by multiplying the cross section by the gap survival factor  $S_G = 0.15$ . More details about EDD production of charm quarks can be found in our original paper [22]. In order to compare this predictions with the PHENIX data we have applied the same procedure of hadronization and semileptonic decays as in the case of inclusive processes described briefly in subsection II A.

### III. NUMERICAL RESULTS

Let us come now to the presentation of our results. In Fig.5 we show distribution in dielectron invariant mass. We have included several mechanisms. The solid lines represent the contribution of charm (upper one) and bottom (lower one) production calculated using the Kwiecinski UGDFs and subsequent semileptonic decays which was calculated in the way described in subsection II A. The Drell-Yan contribution is shown by the long-dashed line and its contribution is comparable to the contribution of semileptonic decays. The gamma-gamma contributions (sum of the four contributions of diagrams in Fig.3) is shown by the blue dashed line at the bottom-left corner of the figure. The very small EDD contribution is shown for completeness by the green dotted line.

In Fig.6 and Fig.7 we present the same distributions but here the calculation of heavy quarks is performed with the KMR and Kutak-Stasto UGDFs, respectively. One can see that the KMR UGDF gives quite good description of the PHENIX data in the whole considered dielectron invariant mass range. Similar results have been obtained with the Kwieciński UGDF except very low dielectron invariant masses. Figure 7 shows that the Kutak-Stasto UGDFs reproduce the experimental data only at large dielectron invariant masses but that is the region where Drell-Yan mechanism gives significant contribution. As was mentioned by the authors of [14], the Kutak-Stasto UGDF is dedicated exclusively to small- $x$  processes ( $x < 10^{-2}$ ), so its use for RHIC is at the border of its applicability, especially for bottom quarks. In the calculation of heavy quark/antiquark we have taken  $m_c = 1.5$  and  $m_b = 4.75$  GeV, rather conservative values.<sup>1</sup>

In Fig.8 we show separately contributions of different photon induced mechanisms shown in Fig.3. The amplitude of the double elastic contribution is calculated as explained in subsection II C, the other contributions are calculated in the collinear approximation as explained in the same subsection.

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<sup>1</sup> Often too small values of heavy quark masses are taken in the calculation to describe the data.

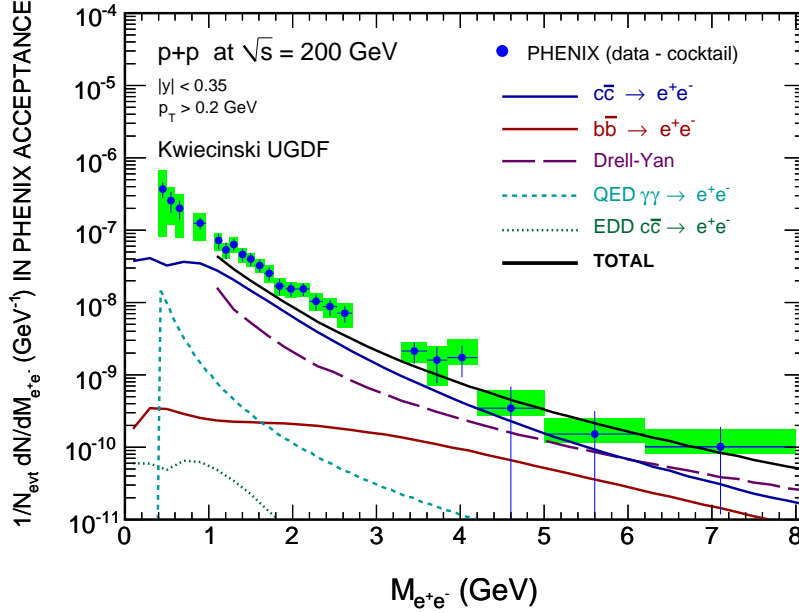


FIG. 5: Dielectron invariant mass distribution for proton-proton collisions at  $\sqrt{s} = 200$  GeV. Different contributions are shown separately: semileptonic decay of charm by the upper solid line (blue online), semileptonic decay of bottom by the lower solid line (red online), Drell-Yan mechanism by the long-dashed line, gamma-gamma processes by the short-dashed line (blue online) and the EDD contribution by the dotted line (green online). In this calculation we have included azimuthal angle acceptance of the PHENIX detector [1].

In Fig.9 we discuss uncertainties related to the contribution of semileptonic decays. Complementary the left panel presents uncertainties due to the factorization scale variation as described in the figure caption. The right panel shows uncertainties due to the modification of the heavy quark masses ( $m_c \in (1.25 \text{ GeV}, 1.75 \text{ GeV})$  and  $m_b \in (4.5 \text{ GeV}, 5 \text{ GeV})$ ). Figure 10 presents uncertainties of our predictions related to the different models of heavy quark fragmentation. Two bands (blue online and red online for charm and bottom, respectively), estimated with Peterson fragmentation functions show sensitivity of our results to the variation of  $\epsilon$  parameters in intervals specified in the figure. The long-dashed lines represent Braaten et al. perturbative fragmentation model and dotted lines are for the fragmentation function proposed by Kartvelishvili et al.. For each of the function we use parameters taken from the literature [26, 27]. As one can observe, in comparison with uncertainties discussed before there is only a small sensitivity of the results to the fragmentation functions. Some small differences start to appear only at large dilepton invariant masses where the error bars of the experimental data are really large. Besides, in the case of bottom quarks such effects are almost negligible.

Since the transverse momenta of electrons can be measured, one can look not only at their distributions but also at correlations between them. In Fig.11 we show two-dimensional distribution in transverse momenta of  $c$  and  $\bar{c}$  (left panel),  $D$  and  $\bar{D}$  mesons (middle panel) and  $e^+$  and  $e^-$  (right panel). In contrast to leading-order collinear QCD calculations already the distribution at the parton level is dispersed along diagonal. It is further broadened by (assumed independent) fragmentation process and even more by (assumed independent)



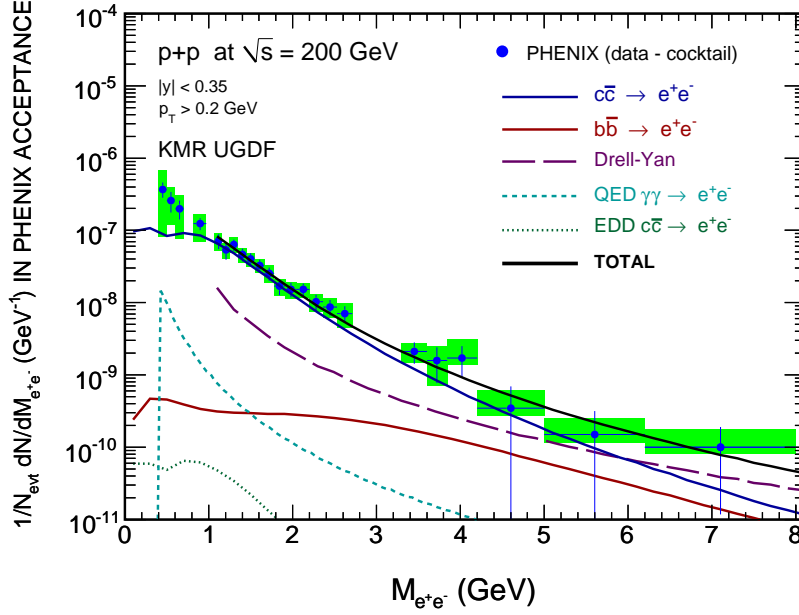


FIG. 6: The same as in Fig.5 but open charm and bottom components are calculated using KMR UGDFs.

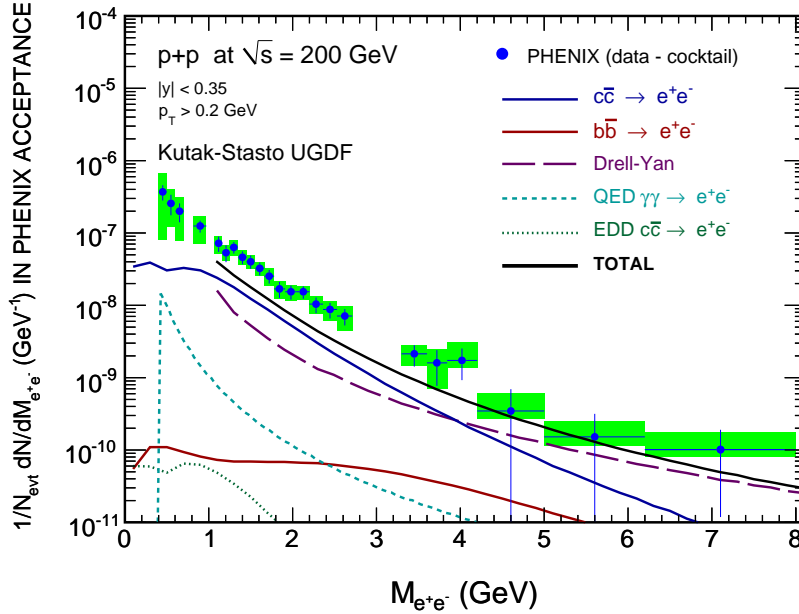


FIG. 7: The same as in Fig.5 but open charm and bottom components are calculated using Kutak-Stasto UGDFs.

semileptonic decays. So the initial transverse momentum correlations of  $c$  and  $\bar{c}$  are practically lost when going to the electrons/positrons but are interesting and provide a new possibility to test the dynamics of the process and our understanding of QCD at work.

If the detector can measure both transverse momenta of an electron/positron and its di-

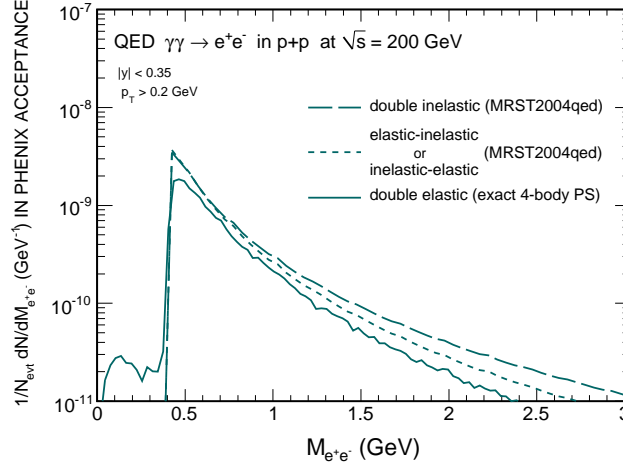


FIG. 8: Contributions of photon-induced mechanisms to the dielectron invariant mass distributions. The PHENIX detector limitations are given in the upper-left corner.

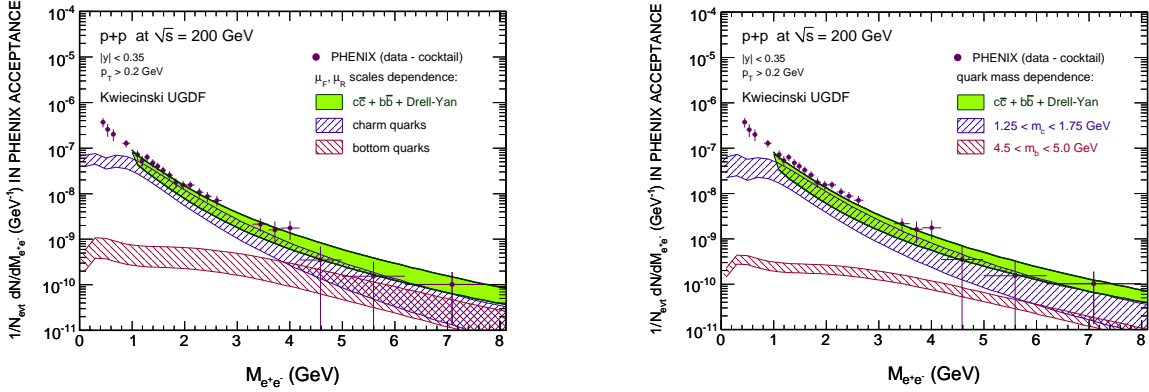


FIG. 9: The uncertainties of theoretical calculations. The left panel shows the factorization scale uncertainties, the lower curve corresponds to  $\mu_F^2, \mu_R^2 = m_{1,t}^2 + m_{2,t}^2$  and the upper curve to  $\mu_R^2 = k_t^2$ ,  $\mu_F^2 = 4m_Q^2$ , where  $k_t$  is gluon transverse momentum. The right panel shows the quark mass uncertainties as indicated in the figure.

rections, as the STAR detector at RHIC can do, one can construct a distribution in transverse momentum of the dielectron pair:  $\vec{p}_{t,sum} = \vec{p}_{1t} + \vec{p}_{2t}$ . Our predictions for the semileptonic decays and Drell-Yan processes are shown in Fig.12. Both processes give rather similar distributions. To our knowledge the distributions of this type were never measured experimentally as they cannot easily be compared to the calculations in the collinear approach due to its inherent singularities. Obviously this is not the case for the  $k_t$ -factorization approach discussed in the present analysis. The distribution in  $p_{t,sum}$  is not only a consequence of gluon transverse momenta, as it is for quark and antiquark production, but involves also fragmentation process and semileptonic decays. A measurement of this quantity would test then all stages of the process.

With good azimuthal granulation of detectors one could construct distribution in azimuthal angle between electron and positron. Our corresponding predictions are shown in

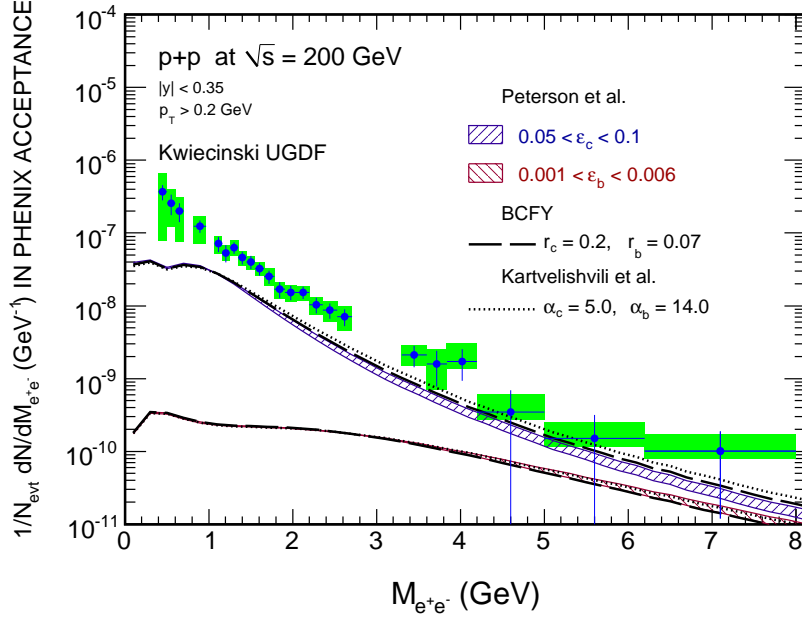


FIG. 10: The uncertainties of theoretical calculations of open charm and bottom related to the choice of the fragmentation functions. BCFY means that fragmentation functions from Ref.[17] were used.

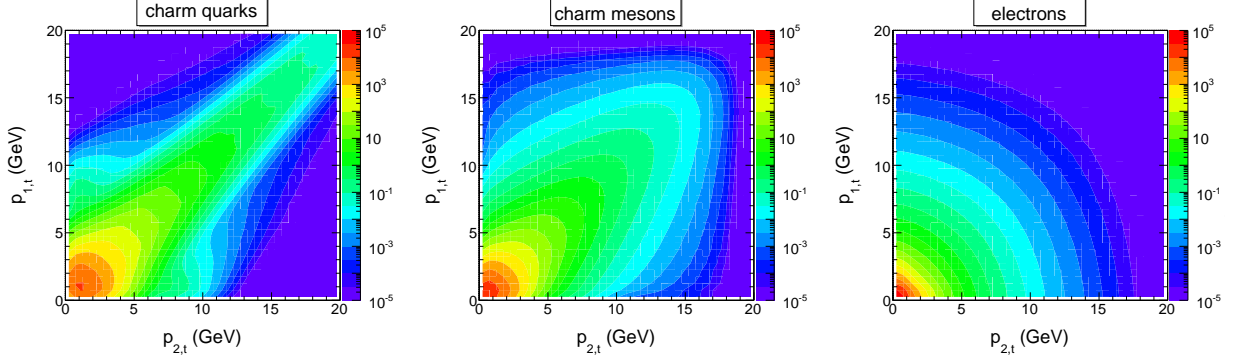


FIG. 11: Two-dimensional distribution in transverse momenta of  $c\bar{c}$  (left panel),  $D\bar{D}$  (middle panel) and  $e^+e^-$  (right panel). Here Kwiecinski UGDF and Peterson fragmentation function were used.

Fig.13. One can see an interesting dependence on the invariant mass of the dielectron pair – the smaller the invariant mass the large the decorrelation in azimuthal angle.

#### IV. CONCLUSIONS

In the present analysis we have discussed correlations of charmed mesons and dielectrons at the energy of recent RHIC experiments. We have calculated the spectra in dielectron invariant mass, in azimuthal angle between electron and positron as well as for the distribution in transverse momentum of the pair. The uncertainties due to the choice of UGDFs, choice

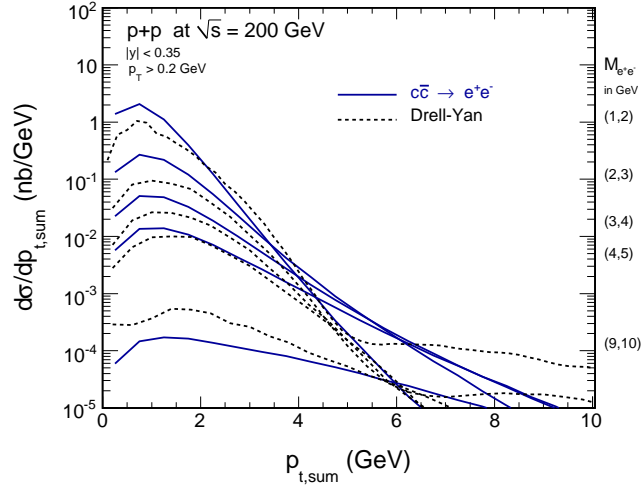


FIG. 12: Distribution in transverse momentum of the dielectron pair for semileptonic decays (solid line) and Drell-Yan processes (dashed line). Here Kwiecinski UGDF and Peterson fragmentation function were used.

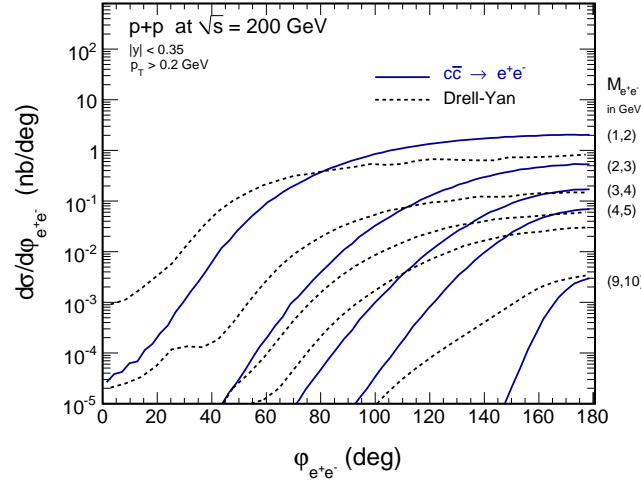


FIG. 13: Distribution in azimuthal angle between electron and positron for semileptonic decays (solid line) and Drell-Yan processes (dashed line). Here Kwiecinski UGDFs and Peterson fragmentation functions were used.

of the factorization and renormalization scales, choice of the heavy quark masses as well as fragmentation functions have been quantified. The uncertainties for UGDFs are larger than those for fragmentation functions. We have obtained good description of the dielectron invariant mass distribution measured recently by the PHENIX collaboration at RHIC.

The contribution of electrons from Drell-Yan processes is only slightly smaller than that from the semileptonic decays. The distributions in azimuthal angle between electron and positron and in the transverse momentum of the dielectron pair from both processes are rather similar. We do not find a possibility of a clear separation of both processes. It was found that the distribution in azimuthal angle strongly depends on dielectron invariant mass.

We have also included exclusive double-diffractive contribution discussed recently in the literature. At the rather low RHIC energy it gives, however, a very small contribution to the cross section and can be safely ignored. It may not be the case at the LHC energy, as the EDD contribution grows much faster than the inclusive cross section.

The QED double-elastic, double-inelastic, elastic-inelastic and inelastic-elastic processes give individually rather small contribution but when added together are not negligible especially at low dielectron invariant masses where some strength is clearly missing [1].

In the present analysis we have studied correlations between electron and positron and in some cases between mesons. It can be also interesting to look at correlations between a  $D$  meson and electron. This will be a subject of a forthcoming analysis.

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